Art. III.—*The Occurrence of So-called Obsidian Bombs in Australia.*

By R. H. WALCOTT, F.G.S.

(Plates III. and IV.)

[Read 9th June, 1898.]

In writing this paper I have been mainly influenced by a desire to draw attention to these most interesting and, in many respects, remarkable objects, in order, if possible, to satisfactorily solve the mystery surrounding their origin. It is, without doubt, a subject which presents many difficulties, and I do not purpose attempting an explanation to account for them, simply because at the present time sufficient data are not obtainable to establish definitely any acceptable theory. I will, therefore, only discuss the explanations put forward by others, and give the conclusions which I have drawn from my own observations. The term "bomb" has been generally applied to these objects, but I think it is justly open to objection, inasmuch as it conveys the idea of a terrestrial volcanic body; and as we have no positive proof that they are products of this nature, the name may be misleading. As long as this uncertainty exists, some other name would be more appropriate, and I suggest and will refer to them in this paper as "obsidianites," a term which will at least not be open to this objection, and will be more convenient for use. As far as can be ascertained, little seems to have been done in the past towards unravelling the true nature of obsidianites—no doubt owing to the obstacles which are at once encountered. They appear to have been first mentioned by Charles Darwin,[1] who described a button-shaped specimen which had been given to him by Sir Thomas Mitchell. It was found on a great sandy plain between the rivers Darling and Murray, and at a distance of several hundreds of miles from any known volcanic origin. He states: "It seems to have been embedded

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[1] Geological Observations on Coral Reefs, Volcanic Islands, and in South America, 1851 ed., pp. 38, 39.

in some reddish tufaceous matter, and may have been transported either by the aborigines or by natural means. The external saucer consists of compact obsidian, of a bottle-green colour, and is filled with finely-cellular black lava, much less transparent and glassy than the obsidian."

Darwin also mentions some obsidian balls described by F. S. Beudant,[1] which are never more than six or eight inches in diameter, and are found strewn over the surface of the ground. Their form is always oval; sometimes they are much swollen in the middle, and even spindle-shaped. Their surface is regularly marked with concentric ridges and furrows, all of which on the same ball are at right angles to one axis; their interior is compact and glassy. Beudant supposes that masses of lava, when soft, were shot into the air, with a rotatory movement round the same axis, and that the form and superficial ridges of the bombs were thus produced.

The Rev. W. B. Clarke,[2] in speaking of the specimen described by Darwin, says that it would seem either to have been drifted from a very long distance, or, which is more likely, from the known habits of the aboriginals, to have been dropped by one of them, who probably found it in the trap hills of the Lachlan, to the north eastward. This specimen was unique as to Australia until recently (at time of writing). The first which Mr. Clarke met with was found in the cradle of a gold-washer on the Turon River, who dug it from a depth of thirty feet below the surface. A somewhat similar specimen was found in the washing-stuff of the Uralla or Rocky River, county of Hardinge, New England District. From the same locality two other specimens were derived. They appear as if they had been cast in a mould; but there is no reason to doubt the imputed origin.

With regard to the Uralla specimens, Mr. Clarke thinks it possible, from the contour of the country and the geological structure, that they had their origin in an outburst of trap (basalt) which caps the ranges in the neighbourhood, and has issued from and overflowed the granite. He considers this more satisfactory than associating them with an intrusion of various

1 Voyage Minéralogique et Géologique en Hongrie, 1818, tom. ii., p. 214.

2 On the Occurrence of Obsidian Bombs in the Auriferous Alluvia of N.S.W. Quarterly Jour. of Geol. Soc., vol. xi. (1855), p. 403.

trappean, porphyritic, and trachytic rocks which occurs about four miles further south, because the detritus is all local and there is no easily assignable crater.

"Whether this explanation is sufficient or not, the facts themselves are interesting, for these singular bodies have been found in three localities in Australia, at intervals of 455 and 205 miles apart—the distances from the Murray and Darling Plain to the Turon, and from the Turon to the Uralla. That they could have had only one point of origin is scarcely to be supposed, if they are really of sub-aërial volcanic origin. In two of the three localities, at least, there is presumption of such action ; and in both of these localities the bombs are embedded in gold deposits."

In the Melbourne Intercolonial Exhibition Catalogue,[1] 1866, mere mention of their occurrence is made as being abundantly distributed over the surface of the basaltic plains round Mount Elephant and Mount Eeles[2] (? Eccles), and on the tertiary mud plains of the Wimmera, far removed from any known basaltic craters or points of eruption. Some analyses are also given, but will not be referred to now. In the descriptive catalogue of the rock specimens and minerals in the National Museum, 1868, mention is made of a remarkable obsidian ball found in the Upper Regions Station, Horsham. On account of its low specific gravity, 1·06, it was deemed advisable to have it cut, but unfortunately no means were taken to collect the enclosed gas. It now shows a cavity having a beautiful polish, and may be seen in the collection of Victorian minerals in that Museum. This specimen will be fully dealt with subsequently.

Professor Tate[3] inclines to the opinion that their distribution has been effected by human agency, and mentions that they are held in high estimation by the aborigines, but considers that the

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1 Notes on the Physical Geography, Geology and Mineralogy of Victoria, by Alfred R. C. Selwyn and George H Ulrich, p. 65.

2 No such mountain is known in Victoria, and it is presumed that Mount Eccles is meant. Prof. Ulrich, who was at that time engaged on the geological survey of the colony, says that the name was given to him by Mr Selwyn, who collected a number of obsidian buttons there, but that if a basaltic point named Mount Eccles is given on the maps situated on the western plain towards Warrnambool and in the neighbourhood of Mount Elephant, we would be justified in concluding it to be the correct one. There is no doubt that the names apply to the same mount, as in Selwyn's map Mount Eeles is in the position given to Mount Eccles in other maps.

3 Trans. Philosoph. Soc. Adelaide, S. Aust., vol. ii. (1879), pp. 70, 71.

evidence is not conclusive till they shall have been traced to their natural sites. He says they have been collected at distant parts of the colony, occurring either loose on the surface or embedded in the "crust limestone."

Mr. H. Y. L. Brown, in the Catalogue of South Australian Minerals, 1893, states that obsidian "has been found in alluvium and on the surface generally in round, button-shaped pieces all over the province, although most frequent in the stony downs and table-hill country of the far north, where its presence, so far away from any volcanic centre, is most difficult to account for."

Victor Streich,[1] who was geologist to the Elder Exploring Expedition, states "that two specimens of the well-known obsidian bombs, and of the usual shape, were collected, one at Birksgate Range and one near Mount Squires. No clue could, however, be obtained as to the original site, or in explanation of their wide-spread occurrence." In some supplementary notes to this paper on the rock and mineral specimens collected, Professor A. W. Stelzner, in dealing with the obsidian bombs found between Everard Range and Fraser Range, says that they are "most decidedly not of cosmic origin, as suggested by you in your private letter to me. At least, so far there are no vitreous masses known to me of meteoric origin. According to their shape, I am inclined to pronounce them as water-worn, and I should think that the obsidian, from which they are derived, will be found yet *in situ*. I cannot say anything more about them without any knowledge of their occurrence."

Subsequently Professor Stelzner received other specimens for examination and further information, and as a result he published an elaborate paper[2] on the subject. He also wrote a lengthy letter to Victor Streich, who had forwarded the obsidianites to him. Five of these were collected at the McDonnell Ranges and the sixth, a hollow one, was found on Kangaroo Island. The substance of the letter is practically the same as the paper, and therefore need not be specially referred to apart from it. Professor Stelzner, who believes these objects to be genuine volcanic bombs, points out certain resemblances to the Bohemian

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1 Trans. of Royal Soc. of S. Aust., vol. xvi. (1893), p. 84.

2 Ueber eigenthümliche Obsidian-Bomben aus Australien. Zeitschrift der Deutschen Geologischen Gesellschaft, xlv. Band, 1893, p. 299.

moldavites,[1] and that the origin of both is enveloped in mystery, but does not think the comparison admissible, as he believes the moldavites' surface sculpture is secondary, whilst the Australian specimens is primary; and, further, that the moldavites possess most variable shapes, and therefore can only be regarded as fragments of larger bodies. The reason which induces him to accept their volcanic origin is based upon the undeniable conformity of general form which the specimens examined exhibited. With regard to the hollow specimen, he says that an exact parallel case of such a natural glass is not known to him either from literary descriptions or from collections, but one is reminded of certain bombs formed of pumiceous material as something nearly akin; for example, the glass balls of black, floating pumice observed by Leopold von Buch[2] in the tuff rocks north of Rome. He also mentions the volcanic bombs from Ascension described by Darwin. He discusses and dismisses the comparison with marekanite from Ochotzk. This is a pitchstone, with kernels of obsidian, from which the latter have become freed by weathering. In referring to other analogous cases, he gives a sentence which occurs in a review of the work of W. Stokes.[3] It is as follows:—"Drops of Vesuvian lava are said to have been found sometimes, and of perfectly globular form. Generally, though they appear somewhat flattened and elongated, at the same time they are surrounded by a projected zone studded with small knobs. These deformities depend upon the degree of viscosity of the descending mass, and the nature of the ground upon which such specimens alighted. Forms resembling these are produced by the rim cooling first." Reference is

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1 Professor Rutley (Quart. Jour. of Geol. Soc., vol. xli. (1885), pp. 154, 155) says that Bouteillenstein (Moldavites) occurs in small, irregularly-shaped nodules and grains in sand near Moldauthein, in Bohemia, in tuffs in the neighbourhood of Mont Dore les Bains and Pessy in the Auvergne, and in one or two other localities. These nodules have peculiarly pitted, corrugated, or wrinkled surfaces. That Bouteillenstein is obsidian is denied by Makowsky (Ueber die Bouteillensteine von Mähren ū Böhmen, in Min. Mittheil, vol. iv., p. 43). Prof. Rutley considers the comparison of Moldavites with fulgurites not merely admissible, but positively instructive. However applicable it may be in that case, I do not think it can be applied to obsidianites.

2 Geognostiche Beobachtungen auf Reisen durch Deutschland und Italien, 1809, ii., p. 51.

3 Ueber Kugelige Bildingen mineralischen substanzen, Neues Jahrb, f. Min. etc., 1836, p. 78. Also Jour. of Geol. Soc. of Dublin, vol. i., pp. 1-15.

also made to the obsidian balls from Mount Patko, Hungary, previously mentioned as being described by F. S. Beudant.

Darwin considers the form of the bombs to be due to rotatory flight, in the centrifugal force engendered thereby, and in the final bursting of the bomb; but with this view Professor Stelzner does not agree, and he regards the final bursting as really objectionable. He admits, however, that rotation may have taken place, although he does not think it necessary.

According to him, the outline form of five specimens can be deduced from that of a sphere, and that of one to a triaxial ellipsoid. He considers that the approximately spherical form was produced in two very different ways. In the one case—that of the hollow ball—it has been produced by the expansion of a thread of lava rich in gaseous components; in the six solid bombs the form is referable to the same causes which induce the shape of a drop of water, or fluid lead descending from a tower or into a shaft, and forming shot globules. He further states that the shape must have been likewise influenced by the resistance of the atmosphere which the rapidly moving bomb had to surmount. In this the explanation of the special form and the more delicate surface sculpture has to be sought for. He then goes on to compare the obsidianites with meteorites, and considers it perfectly admissible. In this he mentions the black, glassy crust, the pittings and the analogy to the expansion rims and streaked friction planes which Daubree[1] obtained in his experiments. Finally, he thinks their origin is to be sought for in Australia, but leaves it to Australian geologists to settle.

Professor Tate and J. A. Watt, in their report on the Geology of the Horn Expedition, 1897, in referring to the numerous obsidian bombs, which most frequently occur in an eroded state, and unrolled agates found between the Stevenson River and Charlotte Waters, say—"In the first place, the occurrence of (*sic*) the obsidian bombs and agates on the Desert Sandstone plateaux and their slopes could not have been transported there by water, unless in the form of ice (an hypothesis incompatible with the co-ordinate features)." They therefore assume that these agates and bombs are all that now remain of a supposititious

[1] Etudes synthétiques de géologie expérimentale, 1879.

volcanic formation, but admit that "the theory seems wild in the extreme, because of the widespread silicification, and the absence over its area of any traces of actual volcanic outbursts."

In "Nature" of 13th May, 1897, there is a review of a paper[1] by Mr. R. D. M. Verbeek, in which he dealt with the glass balls of Billiton:—"In the quaternary or, perhaps, pliocene tin ore deposits of Billiton there occur peculiar rounded glass balls with grooved surfaces; they are also found, though very rarely, in certain quaternary tuff strata in Java and in the equally quaternary gold and platinum mines of South-eastern Borneo." The author classed these objects with the Bouteillenstein of Bohemia and the quaternary glass balls found in Australia. He believes that they cannot be of volcanic origin, because the nearest volcanoes are too far distant, and have, moreover, produced glassy rocks of quite a different nature. For various reasons they cannot be artificial either; he therefore takes them to be of non-terrestrial origin, and considered it probable that they are thrown out by lunar volcanoes during the quaternary and, perhaps, already during the pliocene period. The most recent paper on this subject, by Messrs. W. H. Twelvetrees and W. F. Petterd, was read before the Royal Society of Tasmania at Hobart in August last. Obsidianites have been found on both east and west sides of the island, as in the tin drift at Thomas' Plain and at Long Plain, near Waratah. The authors state that "the strange feature of the Tasmanian occurrence is that no glass of similar igneous rocks was known in the island, nor any trace whatever of tertiary or recent rhyolite or trachyte." They consider that they are unquestionably volcanic products, but think that the inference that the volcano was a lunar one was unnecessary, and was open to objection. The terrestrial volcanic hypothesis "only required that the molten spray should have been carried by winds as far as Tasmania and Australia."

Before considering these papers, it will be well to settle, as far as possible, the chemical nature of obsidianites, more especially as doubts have been expressed on this point, and to give a description of the various forms met with. As far as is known,

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[1] Read before the Koninklijke Akademie van Wetenschappen, Amsterdam, 27th March, 1897. See also Jaarboek van het Mijnwezen, in Nederlandsch Oost-Indië, Amsterdam, pp. 235-272, pl. i., 1897.

only two complete analyses appear to have been made, viz., Nos. 1 and 2 of the following list :—

	No. 1.	No. 2.	No. 3.	No. 4.
Silica - - - -	73·70	64·68	71·38	73·40
Ferrous Oxide -		1·01	} 19·36	} 4·74
Ferric Oxide - -	6·08	6·57		
Alumina - -	4·99	16·80		12·65
Manganese Oxide -		·20		present
Lime - - -	4·20	3·88	2·86	4·30
Magnesia - -	·10	2·50	1·89	·74
Soda - - -	5·20	trace		
Potash - - -	4·83	4·01		
Loss by ignition -	·55			
Total - -	99.65	99·65	95·49	95·83
Specific Gravity	2·47		2·44	2·47

No. 1. Analysis of a Wimmera specimen made by the late J. Cosmo Newbery, and published in the Melbourne Exhibition Catalogue, 1866.

No. 2. Analysis of a specimen from Uralla, N.S.W., made last year by Mr. J. C. H. Mingaye, and forwarded to me by the courtesy of Mr. E. F. Pittman, Government Geologist of that colony.

No. 3. Partial analysis of a specimen from Mount Elephant, made by Mr. F. Stone, Assayer to the Mines Department.

No. 4. Partial analysis made by the author of a specimen from Central Australia, collected by Professor Spencer.

The silica percentages shown by these analyses should prove indisputably their acid nature; even No. 2, with its lower silica contents, makes it an undoubted glassy representative of the trachyte series. The term acid is now used, not perhaps in its generally accepted sense, but only in contra-distinction to basic, which includes eruptives carrying up to about 55 per cent. silica. As a matter of fact, it seems probable that a number of specimens belong to the intermediate series. Mr. George W. Card, Curator of the Geological Museum, Sydney, has pointed out that, while the low percentage of silica in No. 2 brings it within the intermediate group, there is a total absence of soda, which is certainly unusual, considering that the felspars of that group are of the soda-lime type. It is to be regretted that so little has been done in their chemical examination, because it is quite possible that each occurrence may present features in common, while differing from those of others. We should also be able to ascertain whether any divergence from ordinary obsidian can be established. Tested for fusibility, the edges and corners of the fragments became rounded, and in thin splinters a light-coloured glass was obtained, whereas basic glasses fuse readily to a dark opaque glass. The range observed in the specific gravity, although mostly inclining towards rhyolite, is still high for rhyolite-glass, and is more consistent with a trachyte or andesite glass, but the maximum obtained by Clarke is undoubtedly that of a basic glass.

He found them to vary from 2·42–2·7, Stelzner from 2·41–2·52, Twelvetrees and Petterd from 2·45–2·47; and from a number of specimens from different parts of the colonies I obtained from 2·42–2·48. All these experiments were evidently made on whole or fragmentary samples, so that, in some instances, the presence of gas vesicles may have slightly influenced the result. Microscopic examination proved it to be a pure glass, with at times scattered vesicles, but no microliths were observed. Vertical and horizontal sections cut from a button specimen revealed, even without aid of the microscope, a peculiar structure. It consists of a number of cloudy, narrow, more or less contorted bands at places closely intermingling. Mr. A. W. Howitt, who was good enough to examine these slides for me, says that under crossed nicols they slightly admitted light, and may therefore be due to strain. Mr. E. G. Hogg expressed the same opinion. Messrs. Twelvetrees and Petterd also observed this structure, and attribute the same cause to it. If it really represents the presence of internal strain, it must have been produced by rapid cooling, but obsidianites certainly do not exhibit any unusual degree of brittleness; in fact, rather the reverse for substances of their nature. It is open to question whether this is a natural structure or an artificial one produced in the preparation of the section; some of it is undoubtedly due to the latter cause.

Some confusion has existed in the part between the occurrence of obsidian and tachylyte in Victoria, and in some of the mineral catalogues localities are given for the former when it should unquestionably have been the latter. In the 1866 catalogue already referred to, two other analyses are given of obsidian from near Geelong, which show respectively 72·23 and 68·45 per cent. silica. Professor Ulrich informs me that Daintree also analysed some volcanic glasses from that neighbourhood and found them to vary in silica from 50 to 70 per cent. As natural glasses are only forms of lava which have cooled rapidly, they must in composition be identical with the devitrified or crystallised forms with which they are associated, and from the amount of silica shown by their analyses we would at least expect to find trachyte in that part, but instead of this being so it is stated that they occur in a basalt quarry in patches and irregular veins of an inch or more in thickness, of generally a black to brown, sometimes a bluish-grey colour. The specimens marked 24 and 24*a* are in the National Museum Collection of Victorian Minerals, and it is from a portion of these that the analyses were made. No. 24 is opaque and of a dark grey colour. It contains peculiar spherules of a devitrified vesicular character, the glass itself being quite homogeneous and free from vesicles. It is readily fusible to a rather frothy glass. By analysis I obtained 53·2 per cent. of silica, and this, with its easy fusibility and other characteristics, should place it within the tachylyte group. Mr. O. R. Rule informs me that there was only a small quantity of this variety found, although he had spent much time in search of it. I think I might therefore be justified in saying that, so far as we know at the present time, with the exception of obsidianites, acid volcanic glass, or obsidian, does not exist in Victoria.

Obsidianites may be briefly described as small bodies of dense obsidian, of regular but varying form, which are found in alluvial drifts and scattered over various parts of Australia and Tasmania. The largest I have seen of the spherical ones measures 59 mm. in its greatest diameter, and of those with an elongated form, one in the Warrnambool Museum measures 90 mm. in length. They are, however, mostly of a smaller size. The most characteristic form is that bearing a marked resemblance to a button, a fact to which the term, "obsidian button," frequently applied to them, is due. This obsidianite may be said to consist of a flattened spherical centre surrounded by a marginal rim, which on the one side forms the continuation of the spherical surface, and when viewed from that side, as a rule, no indication of it is seen. This side shows generally a number of successive circular flat grooves, sometimes forming a distinct spiral. The other side exhibits the rim surrounding the central portion, which is always more or less pitted. These pittings, which are usually scarce on the rim and under side, are small and frequently of perfect hemispherical shape. The rim is sometimes quite smooth and regular on the outer edge, forming a complete ring, or else broken and irregular, but it always shows a depression or trough all round. With two exceptions, for one of which see Pl. III., Fig. 8, this is the only form observed with this rim. Most of the others are round (Figs. 4 and 5, Pl. III.), oval or elongated (Figs. 1 and 2, Pl. III.) in general form, the latter ones being contracted in the centre, at times roughly resembling a dumb-bell. The top and bottom are more or less convex, the bottom, or smaller section, being always of greater convexity than the top. They are both pitted to a greater or lesser extent, sometimes like that in the specimen next described, or in a more regular manner. The sides are rudely corrugated or furrowed in an approximately vertical direction, and slope at various angles, but they can be traced in a series of specimens to gradually become merged into part of the lower convex surface, in which instance the obsidianite assumes the form of two hemispheres of unequal diameter joined together, and we have a more or less spherical body. The corrugations are then much less conspicuous and at times almost obliterated. The sides show fewer pittings than either top or bottom. Without doubt the most interesting form met with is that of the hollow obsidianites. The one from Kangaroo Island has been fully described by Stelzner, but no description appears to have been given of the Horsham specimen (Figs. 1 and 1A., Pl. IV.). This obsidianite, in its greatest diameter across the peripheral ridge, measures 59 mm., and at right angles to this, 52·5 mm. In shape it is approximately spherical, but it has the characteristic form just mentioned of two hemispheres of unequal diameters joined together. The larger section is generally smooth and marked with pittings crowded into irregular bands or patches enclosing smooth elliptical centres. The smaller section shows the peculiar corrugations commencing immediately under the peripheral ridge, but gradually fading away as the centre of the section is approached. The pittings are also present, but to much lesser extent and more equally distributed. It also shows marks or short grooves, in their arrangement somewhat resembling Hebrew characters, commencing at a slightly raised centre and radiating in six irregular lines towards the ridge. These grooves are also noticed in other specimens. The smooth elliptical centres referred to above are also outlined by fine groovings in places passing through the pits. In some instances the pittings themselves have the appearance of being drawn out, forming short grooves parallel to the fine markings.

Another feature is that some of the pits are contained within others. The interior of the obsidianite, which is slightly egg-shaped, has its greater diameter of 47·5 mm. in the direction of the smaller outside diameter. The other inside diameter measures 44·5 mm. It is perfectly smooth and has a high polish The obsidian is quite dense, with the exception of a few scattered vesicles, and is of a brownish colour in transmitted light. One or two points in connection with this specimen are worthy of mention. In general external form it differs only in being rather more spherical than other solid specimens, and in this respect, to all intents and purposes, they may be regarded as identical. This being so, it is evident that the presence of the cavity cannot have had any influence of consequence upon its configuration. The vesicles contained in the wall are spherical and small and few in number. Had the obsidianite been produced from a fragment of lava rich in gaseous components, the walls would surely have been highly vesicular, with a tendency for the vesicles to be drawn out in a direction coincident with the surface.

A striking feature in this specimen is the remarkable difference shown between the two sections. They are sharply defined by the ridge, as if two diverse agencies were at work in their formation. With regard to an explanation for the production of the button-shaped, or in fact any, specimens it must to a great extent be hypothetical, but what is now advanced is the result of the examination of numerous specimens from all parts. Of these, a number seemed to suggest a series in the development of button forms commencing with the elongated or round types. In the first case, if we assume on ascent or descent, as the case may be, of the plastic material during rapid horizontal rotation, the tendency will naturally be, in these elongated bodies, to cause the material to flow towards the ends by centrifugal force, and at the same time the resistance of the atmosphere might have the effect of pushing back the outside portion of the obsidian from the front or advancing side, and so producing the rim.

Should this action be continued further, the material will go on accumulating at the ends until the centre becomes so weakened and reduced that a separation takes place, resulting in the formation of two incomplete buttons, then if plasticity and flight are still retained, it is reasonable to infer that two complete forms will result. Finally, the rim will be pushed so far as to cause a complete separation between it and the ellipsoid centre (Fig. 9, Pl. III.), and, if conditions are still favourable, a new rim will be formed, and the operation repeated. These solid centres are not uncommon, but only two separated rims have come under my notice.

With the other type, the process would be simpler, comprising only a pushing back of the plastic material in order to form the rim, and give the characteristic button-shape. This is practically the same explanation as that offered by Professor Stelzner to account for the rims, and he compares it to the pushing on of a glove-finger or the form produced by firing a leaden bullet into sand. These forms might then be said to represent various stages in the production of the button obsidianites, and depends primarily upon the shape of the original fragment, upon the degree of plasticity, and, finally, upon the rate of ascent or descent and rapidity of rotation. That they all reached the earth's surface in a solid state seems apparent, because in no instance has any alteration from their symmetrical form been observed, and some modification would have resulted had they landed in a soft or plastic state. Professor Stelzner does not think the assumption of rotatory flight necessary for the production of form as suggested by Darwin, and he compares it to the causes which induce the shape of a drop of water, or fluid lead descending from a tower or into a shaft, forming shot globules, but modified by the influence of atmospheric resistance. I have also assumed that rotation took place, simply because it seemed the most reasonable view to adopt on account of variance exhibited in some specimens, and that a simple progressive motion does not seem compatible with the elongated form with contracted centre. Even in the button-shaped obsidianite, the flat grooving shows at times a distinct spiral, as if it had been turned on a lathe, and in one specimen (Fig. 6, Pl. III.), the upper surface is scored with fine circular lines, or what is probably a fluxion structure due to rotation about a vertical axis. Other specimens have the pits on that surface arranged in a similar manner. I do not therefore think that the causes which induce the spherical form of what could have entirely prevailed, and certainly I have not seen any obsidianite bearing a resemblance to the form of a bomb which has, according to Professor Stelzner, had a simple progressive motion.

The pittings, which are so characteristic of obsidianites, afford interesting matter for investigation. If they were produced at the moment of their origin, before the present forms were attained, which we suppose to be due to their passage through the air whilst in a molten state, it might naturally be expected that they would have thereby suffered elongation and contortion. In the hollow specimen and some of the others to a certain extent, this seems to have taken place when an apparent flow of the material has elongated and drawn the pits into groups and bands so closely crowded as to almost blend into one another. Also on some of the button-shaped obsidianites on the smooth grooved surface no pitting appears, the conclusion being that they were smoothed out or obliterated by the friction of the air against the rapidly moving object. On the contrary, however, other specimens exhibit the pittings equally distributed over the surface, and show no indication whatever of alteration from the regular half sphere, and in one instance two isolated pits of undisturbed form are present on the rim of a most perfect button-shaped specimen. They look very much as if they were caused by some small spherical body falling on the soft material. It is also observed that the grouping which is present in the hollow specimen has been sharply limited by the peripheral ridge, and the pits on the corrugated portion are not affected in the same way. Besides this, the occurrence of pits within others suggests a doubt as to whether they were originated at one time. Again, in Fig. 6, Pl. III., the surface has the appearance of being completely covered with a black coating, as if it has been frosted, but on close examination it is seen to consist of innumerable pits, so closely aggregated as to present no perfect forms. This structure resembles on a small scale the pittings or thumb marks, so well known as characteristic of meteorites. It is more than likely, therefore, that these pits result from a cause acting throughout the time they were in a molten or, at least, a soft condition, even after their ultimate form was assumed, and that they were not due to decomposing agencies at a later period. The corrugations, which, as far as can be ascertained locally, bear a resemblance to the ridges and furrows of meteorites, are always present on the sides of obsidianites, and are approximately vertical in their direction. If they are due to a similar cause, that of a flow of the melted material from front to back, then they could not have been formed by a rapid descent or ascent. Had this been so, they would have been horizontal or otherwise; they would simply be rims, because this is practically how these are supposed to have been formed. It appears, therefore, under this assumption, that they resulted in all probability in a rapid horizontal rotation. Some of the button specimens have a slightly wrinkled appearance on the outside of the rim, as if it were indicative of previous corrugation, which has been partially overcome and modified by the friction due to vertical flight.

The markings on the obsidianites from Central Australia, which were kindly lent to me by Mr. J. A. Watt for examination, differ both in form and distribution from the pittings, and are probably due to a different cause. Their entire surface is completely scored with these small marks, and their general form shows signs of erosion, as mentioned by Messrs. Tate and Watt. The view that these surface markings are secondary is strengthened by the fact that some of the specimens have every appearance of being fractured either by their fall on earth or contact with other substances; but the fractured surface differs in no way from the remainder. If they are secondary, then a cause will be found in the scouring action of the wind-blown sand, which no doubt exerts extensive corroding influences in those parts.

An important fact in connection with the occurrence of obsidianites is their wide distribution, and, if their origin is limited to one point of eruption, it will be evident that some most extraordinary agent must have been employed to spread them over so immense an area. An idea of this may be gained when it is realised that these objects have been reported at Albany in the west and Uralla in the east, or almost at the limits of the continent in those directions. In the north they are recorded from the McDonnell Ranges, and in the south they have been found in various parts of Tasmania. Within these limits their occurrence is reported from many parts. In West Australia, since the discovery of the goldfields, they appear to have been found plentifully scattered over the surface and in the alluvial of Coolgardie and surrounding districts. Victor Streich[1] says they have been collected at Mount Squires, the Fraser Range, in the sandhills of the Great Victorian Desert, and at the Birksgate Range.

According to Mr. H. Y. L. Brown, Government Geologist of South Australia, they occur similarly over the province, more especially in the far north, and Messrs. Tate and Watt found numerous specimens between the Stevenson River and Charlotte Waters. Professor Tate[2] mentions that he has seen a specimen obtained at Gawler, from the centre of a nodule of travertine; and several that were collected about Stuart's Creek, and one from King George's Sound. Pitchstone and obsidian bombs are said by Mr. J. Chandler,[3] of the Peake, to be plentiful on the plains, and Mr. Canham,[3] of Stuart's Creek, reports similar specimens. The hollow specimen described by Stelzner is said to have come from Kangaroo Island. Clarke's record[4] of their occurrence at the Wannon appears to have been the first in Victoria. In the south-west district of this Colony many have been found, as at Mounts Elephant and Eccles. They are

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1 Trans. Royal Soc. S. Aust., vol. xvi. (1893), pp. 84, 94.

2 Trans. Philosoph. Soc. Adelaide, S. Aust., vol. ii. (1879), p. 70.

3 Trans. Roy. Soc. S. Aust., vol. iv. (1880-81), pp. 148, 149.

4 Quart. Journ. Geol. Soc., vol. xiii, 1857, p. 188.

also recorded[1] from a post-pliocene drift at Spring Creek, near Daylesford. Obsidian is said[2] to occur at Ararat and Retreat Creek, Ingleby, but no particulars are given. Specimens in the Warrnambool Museum are labelled from Mount Rouse, Grassmere, and from Mepunga two feet from the surface. Mr. R. G. Johns, of Ballarat, states that they have been found on the surface at Warrnambool, Balmoral, Harrow, and Edenhope, in the Western District; in the auriferous drift near Ararat sixteen feet from the surface, and at Rokewood thirty feet from the surface; also in the shallow workings of the Hard Hills, near Buninyong. He reports the discovery quite recently of an obsidian ring, which was found on bedrock sixteen feet from the surface, at Rocky Point, about eight miles from Ararat. Mr. T. S. Hart, of the Ballarat School of Mines, has kindly given me the following list of localities from which the specimens (all of the characteristic button shape) in their Museum were obtained: Telangatuk, north of Balmoral; Glenelg River; Nerring, near Beaufort, found in white clay twelve feet from the surface; Byaduk Creek, Hamilton; and Bolwarrah, Moorabool River. Mr. G. W. Card informs me that they occur at Uralla, N.S.W., in shallow leads and scattered over the surface, but that, although said to have been found in deep leads there, no proof of their so occurring could be obtained. They are also reported from Thackaringa, Tumbarumba, Cobar District, Majors Creek, (Braidwood), and Broken Hill. In that colony the specimen described by Darwin was found between the rivers Darling and Murray, and those mentioned by the Rev. W. Clarke from the washing-stuff of the Uralla, and one from the Turon River, where it is supposed to have come from a depth of thirty feet in the auriferous wash. One in the Technological Museum is said to have come from Mount Oxley. Mr. R. L. Jack, Government Geologist of Queensland, states that obsidian button-bombs have been reported from the Central (Rockhampton) District. In Messrs. Twelvetrees and Petterd's paper it is stated that they occur in the tin drifts of Thomas Plains (East Tasmania); at Long Plains, near Waratah, in an alluvial drift ten feet from

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1 Melb. Intercol. Exh. Catalogue, 1866.
2 Geol. Survey Progress Report, vol. iii. (1876), p. 286.

the surface; at Springfield in a bed of quartz wash six inches thick, overlaid by two feet of alluvium, the whole resting upon granite; in stanniferous drift at Norfolk Range; Camden Plain; Mount Barrow in auriferous wash; and at Lisle in auriferous wash. We have one in the Technological Museum labelled from Back Creek, and Clarke records one from Supply Rivulet, River Tamar. No doubt obsidianites have been found in many other parts of the colonies, and the foregoing is not by any means a complete list, but it is as complete as I can make it from records and personal information. It is however, I think, quite sufficient to convince us that they occur all over the continent, and that they are not restricted to any particular localities, also, owing to their undeniable similarity of form and physical characteristics, that they are invariably products of a like nature and have a common origin. The two theories put forward to account for the phenomena are:—First, that they are terrestrial volcanic products; second, that they are non-terrestrial products or aërolites. It is generally agreed that if of terrestrial origin they are primary volcanic products and are not due to concretionary action in either eruptive or sedimentary rocks. If non-terrestrial, then we can only conclude that they have been derived from celestial bodies which are almost, if not quite, identical with some of our volcanic rocks. To account for their widespread distribution under the first hypothesis various agents are suggested, and in order to deal with this point we will assume that they are products of that nature. Four explanations are offered to account for their distribution, viz.:—By rivers or creeks, by ice, by means of the aborigines, and by the agency of the wind.

Obsidianites occur both on the surface and in the alluvium, and therefore, to a certain extent, there may have been a distribution of water. With regard to the latter occurrence, I have not been able to obtain any authentic information as to the nature of these drifts, except that they are mostly shallow, and that the presence of obsidianites in deep leads, although reported, has not been verified. The specimens examined, which are said to come from the drifts, are not in any way water-worn, and Mr. George W. Card informs me that those found in the alluvial of the Uralla showed no signs of attrition, their preservation being perfect. It seems probable that this feature is really responsible for their being found at all, for had they become rounded and water-worn they would have passed unnoticed amongst the material comprising the wash. Considering their brittle character[1] and the conditions prevailing in transport by water, those which have been so found could not have been transported any distance worthy of mention, and this is consistent with their occurrence in shallow alluvial (post-pliocene), which is generally comprised of comparatively unrolled material derived from the adjacent country. On the other hand, they could scarcely have survived the attrition suffered in the formation of the deep leads, and if they did they would easily escape observation. It is quite evident, therefore, that in this instance the distribution could at the best be only a comparatively limited one, and that they are mostly found at or near the place of original deposition.

Those occurring on the surface, with the exception of the Charlotte Waters specimens, are similarly free from any signs of attrition, and are mostly in a most perfect condition, although some exhibit slightly weathered surfaces.

Independent of this, all other features associated with water carriage are entirely wanting, so that rivers or creeks, either of the past or present, cannot have taken any important part in their distribution.

Icebergs as a distributing agent cannot be considered seriously, as the conditions which would have been assumed are quite out of the question. For instance, we should have to assume that the continent was entirely submerged, over which the icebergs with their loads drifted and there deposited them. We must then suppose that the continent was raised above the water, the surface features being much as they are now, and we must further give the icebergs a monopoly of carrying obsidianites only from their origin, which it has been suggested might be

[1] Mr. J. G. O. Tepper, who translated Stelzner's letter, in a footnote thereto points out, as an objection to volcanic origin, that all molten glasses, lava, slags, etc., if cooled comparatively rapidly in the form of small masses, exhibit great and, mostly, excessive brittleness, which is not the case in the comparatively very small Australian bombs. In fact, they could not have been preserved at all if assumed to have been carried great distances by currents of flowing water and subjected to attrition by violent contact with other rock fragments, if they had not been endowed with a very considerable degree of cohesiveness.

Mount Erebus and Mount Terror, although we have not the remotest idea that they exist there. This manner of distribution is advanced by Mr. Gavin Scoular.[1]

Darwin's suggestion that the specimen he examined may have been transported by the aborigines seems to have received a good deal of support as a general explanation, and in that particular instance the Rev. W. B. Clarke looks upon it as the most reasonable view. Professor Tate also supports this explanation, and submits the following documentary evidence of the value set upon obsidian bombs by the Australian black. A correspondent from Salt River, King George's Sound, states :—"The black stones are very rare and much prized by the natives, who believe the possessor bears almost a charmed life and is able also to cure sick people of any complaint they may be afflicted with, as also to bewitch their enemies, or anyone with whom they have a grievance, tormenting them with all kinds of diseases, and finally destroying life itself." Mr. Canham, of Stuart's Creek, writes :—"With the stones will be found one to which a strange story is attached. I was told by the native I had it from that it was taken out of the breast of a sick man by one of their 'koonkies' or doctors, who, however, did not succeed in saving the patient's life, as some other 'koonkie' of another tribe had a greater power than the one who took the stone out. The sick native I mention died here of disease of the lungs, and all the koonkies in the country could never have saved him." Professor Tate apparently does not think this mode of distribution altogether satisfactory, as he offers quite a different interpretation to account for the presence of obsidian bombs between the Stevenson River and Charlotte Waters.

Messrs. Twelvetrees and Petterd mention that they have been informed that in the Coolgardie district, West Australia, they are collected by the aborigines, and used as charms by pressing them on the part of the body which is suffering pain. Mr. Johns informs me that Mr. Archibald, late curator of the Warrnambool Museum, told him, but in rather vague terms, that they were carried by the blacks as amulets, and sometimes broken up to obtain splinters for barbing spears. Mr. Johns himself does not

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1 Trans. Philosoph. Soc. Adelaide, S.A., vol. ii. (1879), p. 68.

think that they were produced by natural agency, but the shape and superficial appearance suggest a mould in the ground, the sides being formed by slips of bark or wood, which produced the grooves. The plastic material, he supposes, was not poured but pressed into it by a saucer-shaped mould. It is strange, if they have been used by the aborigines as charms or ornaments and so distributed by them, that no authentic record is extant. We hear of them being in the possession of the natives, but I have not been fortunate enough to find anybody who has actually seen them in use. Professor Spencer tells me that he never saw them worn by the natives of Charlotte Waters, where they occur plentifully, and that no notice of them whatever was taken; and even if they were distributed in this way to some extent, it brings us no nearer to the discovery of the point or points of origin, upon which the proof of a terrestrial origin must necessarily depend. As a matter of fact, nowhere within the colonies has any eruptive point, however far distant, been proved to have produced objects of a similar nature from which the aborigines could have obtained them, and therefore they could only have found them scattered on the surface in the manner in which we know them to occur.

Twelvetrees and Petterd's hypothesis, that they might have been distributed by winds, although original, cannot be regarded as a satisfactory solution of the problem. That objects of their size and weight could have been carried by winds from their place of origin, which is assumed to be outside Australia, to their ultimate position is incredible. It is true that volcanic ash may be carried many hundreds, and even thousands, of miles from its place of origin, as was instanced in the last eruption of Krakatoa, in 1883; and in the western States there occur remnant beds of fine volcanic dust, such as must have originally covered many square miles of territory, but the sources from which they were derived are now wholly obscured. In this case, however, we are dealing with a totally different material.

Professor Bonney calculates that it would take from 4000 to 25,000 particles of volcanic dust from Cotopaxi to make up a grain in weight, and it will be well understood that if dust of this fineness reached the upper currents of the atmosphere, it would remain suspended for lengthy periods, and might be then carried immense distances from its source. On the other hand, some of the obsidianites weigh an ounce and more, and heavier ejectamenta such as these would only be subject to a comparatively slight divergence from their original flight.

It is quite evident, from their manner of distribution, that considered as volcanic terrestrial products, obsidianites could not have originated from a single eruptive centre. Neither are we much enlightened by assuming that they were ejected from a number of volcanic points situated within a reasonable distance of the places in which they were found, because many of the occurrences are remote from the nearest points of possible eruption, and we cannot satisfactorily account for their transportation; and is it possible to believe that such extensive denudation took place as to remove all concomitants of a widespread volcanic outburst, and at the same time leave these objects, some of which are in a most perfect state, as the sole representatives. Naturally these small objects would have yielded much more rapidly to decomposing influences than the extensive contemporaneous lava flow, and therefore have been the first to disappear. At Mount Elephant and Mount Eccles in our colony we have them actually occurring within an extinct volcanic area, and it might be thought that they originated from these points. As far as is known all the most recently ejected lavas of this part are basic, and in several parts vesicular bombs abound, but they differ totally in every respect from obsidianites, which we have already seen are acid. Now, as far as experience goes, nowhere within that locality, or indeed within the colony, have acid lavas been found. Some of the obsidianites are quite perfect in every respect, showing not a trace of decomposition, and are found lying upon the basaltic lavas now undergoing decomposition, and which are the products of our most recent volcanoes. Making due allowance for their difference of composition, which enables obsidianites to resist the attacks of decomposition longer than the bombs of a basic nature, it would be strange, if they are contemporaneous, that they are so perfectly preserved. And to assume contemporaneity we must believe that basic lavas and acid bombs were ejected at one and the same time, a state of things most highly improbable. If they really owe their origin to an acidic volcanic outburst, and by some means unknown to us they have been transported to where they are now found, it ought to follow that where we have had extensive volcanic activity of this nature we may reasonably expect products similar in all respects. The nearest occurrence of this kind is in the North Island of New Zealand, where obsidian is very common in the rhyolite series, and an abundance of pumice occurs, but Sir James Hector states that he has never seen obsidian bombs[1] there, and Professor Ulrich says he has never heard of any such button-shaped bombs as the Victorian ones being found in New Zealand. But in regions where basic flows have taken place, bombs occur similar to those of the same nature found here, which are always more or less vesicular.

This fact opens the question whether solid bombs, either acidic or basic, are ejected by volcanoes. In speaking of bombs, I refer particularly to true bombs or masses of lava which have assumed a more or less regular shape through their gyrations in the air whilst in a molten state. I say this advisedly, because not only blocks and fragments of solidified lava may be ejected, but also pieces of foreign rocks through which the pipe burst, and which may differ totally both in physical and lithological character from the ordinary products. In this respect then we have just seen that in New Zealand solid bombs are not known, and it is hardly likely that where such extensive volcanic activity has been displayed they would not have been noticed if they existed. Then, referring to Professor Stelzner's paper, in which he gives a number of analogies, the only ones which can be taken as undoubtedly composed of dense obsidian are the moldavites and the obsidian balls from Mount Patak.

But the strange feature in, anyway, the first instance is that their origin, like the obsidianites, is enveloped in obscurity.

With regard to the second instance, Beudant says that the form of the obsidian specimens presents itself everywhere, which indicates necessarily a like cause in all localities. These specimens were found at the foot of hills composed of pumice and trachyte conglomerates, the latter overlying the former. It is

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1 Professor F. W. Hutton, under the heading of obsidian, mentions a black vitreous volcanic bomb, highly vesicular inside, with a thin cracked vitreous skin on the outside, from Mount Haroharo, Lake Rotoiti, Tauranga Co. Trans. Royal Soc. of N.S.W., vol. xxxiii., p. 23.

asserted they only occur on the surface, and have not been found within the conglomerates. Their source is not mentioned, so that it is not quite certain whether they have been established as true bombs.

Stelzner also describes an obsidian bomb from Mexico, given to him by Rosenbusch, which he compares with obsidianites, but does not think the resemblance of form very close. Unfortunately he gives no particulars of its occurrence or its internal structure, so that we are left in doubt on these points. Darwin, in comparing these objects with the bombs from Ascension Island, was evidently misled, from the examination of a perfect specimen, by the pittings, which bear a strong resemblance to external signs of vesicularity; and Clarke also mentions them as being similar. The hollow obsidianite can scarcely be called vesicular, as the wall, with the exception of a few isolated vesicles, is compact. The smooth, polished interior is sufficient evidence of this. Let us now view the operation by which bombs are originated, and see whether it favours a solid or vesicular character.

Professor Judd[1] gives a graphic description of the phenomena taking place in an active volcano vent, and I cannot do better than repeat it here. It is as follows:—"If we take a tall, narrow vessel and fill it with porridge, or some similar substance of imperfect fluidity, we shall be able, by placing it over a fire, to imitate very closely indeed the appearances presented in the crater of Stromboli. As the temperature of the mass rises, steam is generated within it, and in the efforts of this steam to escape the substance is set in violent motion. These movements of the mass are partly rotatory and partly vertical in their direction; as fresh steam is generated in the mass its surface is gradually raised, while an escape of the steam is immediately followed by a fall of the surface. Then an up and down movement of the liquid is maintained, but as the generation of steam goes on faster than it can escape through the viscid mass, there is a constant tendency in the latter to rise towards the mouth of the vessel. At last, as we know, if heat continues to be applied to the vessel, the fluid contents will be forced up to its edge, and a

1 Volcanoes: What they are and what they teach. 1885 ed., p. 20.

catastrophe will occur, the steam being suddenly and violently liberated from the bubbles formed on the surface of the mass, and a considerable quantity of the material forcibly expelled from the vessel."

Under these conditions the surface of the molten mass must then be constantly traversed by jets of escaping steam, until, as is pointed out, the steam which collects faster than it can be liberated in this manner, frees itself by an explosion of greater or less intensity, carrying with it fragments of the lava. Now this explosion takes place near the surface in the region of the lava, which must necessarily be permeated with steam and consequently in a vesicular condition; it is thereby broken up and partly ejected in the form of vesicular bombs, lapilli and dust. The steam imprisoned in the bombs, during their passage through the air, tends to expand, and they become more or less completely distended with bubbles. This action must be the same no matter what the nature of the lava may be, only that probably in the case of acid lavas the explosive action might be much more violent, owing to their greater viscosity permitting a larger quantity of steam to accumulate and become more highly heated before being expelled. This, then, may have had some influence upon the apparent scarcity of acid bombs; that is to say, the lava in this instance would not be sufficiently fluid, when ejected, to take any very regular form, and would appear more as fragmentary pumice. The difference in the liquidity is evidenced by the fact that basic lavas form much more extensive sheets, sometimes flowing to great distances from the vents, than do the acid lavas, which tend rather to accumulate round the points of eruption. From what has been said it will be seen that the origin of volcanic bombs is of such a character as to reasonably infer that they would mostly be of a vesicular nature, whether acid or basic, and the apparent absence of obsidian bombs in the North Island of New Zealand, and in fact of all solid bombs in that and this colony as well, strengthens the idea.

The forms presented by the obsidianites are so extraordinary and curious that they at once direct attention as being a most unusual natural occurrence. As far as I can gather, most of these forms have not an analogy amongst volcanic ejectamenta, although approximated more by them than anything else known, and therefore this feature alone is of no avail in support of a terrestrial volcanic theory. Even Professor Stelzner admits this when describing the hollow specimen from Kangaroo Island, of which he says that an exact parallel case of such a natural glass is not known to him either from literary descriptions or from collections.

Darwin says that the obsidianite he examined seems to have been embedded in some reddish tufaceous matter. In one specimen from Mount Elephant which has come under my notice I also observed a material bearing a very similar character; but as it comes from a volcanic region, it may have gathered it when it fell, and there would be no special interest attached to its presence. Darwin's specimen, however, came from a part hundreds of miles distant from any known crater, and, if he is correct in his surmise, it certainly is a point in favour of a terrestrial volcanic origin. If this theory is a correct one, little evidence has as yet been brought forward to establish it; but their discovery over such an immense area, their remoteness in some instances from any points of eruption, and the absence of evidence in others that they are due to local volcanic outbursts, and, finally, the want of proof that they have been transported, are in themselves obstacles difficult to explain away by any such hypothesis.

We have now to consider the non-terrestrial or meteoric theory. In the first place, it at once affords a satisfactory explanation of their indiscriminate and widespread mode of occurrence, and for this alone deserves serious attention. Mr. Verbeek goes so far as to say that they may have been ejected from the moon during the quaternary or perhaps pliocene periods, but as this involves a discussion on the origin of meteorites, it would evidently be out of place to offer any remarks about it. Neither is it desirable that we should do so, as we are only concerned generally with a non-terrestrial origin.

Two objections may be urged against this theory, namely, their regular form and their composition, both being entirely different to that obtaining in known meteorites. How the shapes could have been assumed under conditions compatible with a meteoric origin is purely a matter of conjecture. It seems highly probable that in substances of their composition the shapes would be produced after entry into the earth's atmosphere, and that they represent fragments of comparatively large bodies. The enormous sudden temperature which would be generated on impact with the atmosphere would be almost certain to cause the original body to burst, resulting, in all probability, in an almost complete shattering of the body, and also probably complete consumption of the greater portion of it. Under these conditions the astonishing thing is, if they are meteoric, that they should have reached the earth's surface at all. Whether these bodies were originally glassy we cannot surmise, because, as they have been molten throughout, they may have resulted from the melting and rapid cooling of crystallised masses. The supposition of a molten state is certainly an unusual one amongst meteorites, as they bear strong evidence of only having been molten to an insignificant thickness of their surface, although there are instances in which some meteoric stones, or aërolites, appear to have been heated throughout their mass to a high temperature.

If, after the bursting of the original body, the various fragments were in a plastic condition, the shapes might have been induced by the hurling of these fragments through the air in all directions with different degrees of velocity. The time it would take these objects to reach the earth's surface would be extremely small, perhaps only a few seconds, and it might be expected that they would then be in at least a soft state. If this were so it would surely show itself by a flattening or otherwise in altering the original symmetrical form, but, as previously mentioned, in those examined there is no appearance whatever that such is the case. We must then believe that they cooled down with great rapidity, an operation which would have produced an extreme brittleness in a glassy substance—so much so, that a fall on the earth would have completely shattered them. Contrary to this expectation, they exhibit even less brittleness than obsidian from lava flows, which exists in masses and under conditions much more favourable to a slower rate of cooling. Nevertheless, it is most likely that only those survived that fell under favourable conditions and that many others were destroyed on contact with the earth whether of cosmic or terrestrial origin. With regard to their composition, we see that it differs entirely from that of all known aërolites, which are basic and represent the basalts, and more especially the ultrabasic rocks of our earth. But it cannot be said, on account of this, that acid meteorites do not exist, because it is only natural that the more meteorites approach terrestrial rocks in their lithological character and composition, the less likely they are to attract attention. This is supported by the fact that few aërolites are known that have not been seen to fall, whilst, on the contrary, only about nine metallic meteorites or siderites have authenticated origin, and their nature is only recognised by their great difference from our ordinary terrestrial rocks. Now, nine only represents a small proportion of the siderites found, and if we assume that the aërolites which have fallen, but have not been found, bear the same proportion to those found, they must exist in very much greater numbers and have been passed by unrecognised.

It seems probable that obsidianites are not all of the same age, for under similar conditions we find some perfectly fresh, with a black, lustrous exterior, and others again more or less dulled and showing signs of decomposition. Further, their presence in post-pliocene drifts as well as on the surface and their variance in composition tend to support this belief. And under a meteoric hypothesis this is only what might be expected, as non-terrestrial bodies are constantly falling on the earth, and have been doing so in the distant past. The strongest argument against this theory certainly seems to me to be their regular form, which is so completely opposed to all we know of meteorites. Why it should be attained in these and not in others of a different composition, although perhaps equally fusible, is indeed remarkable, but is it not possible that these objects only represent a portion of this interesting occurrence, and that their exceptional shapes are really responsible for their discovery. If, on the basaltic areas of the Western District, irregular fragments of obsidian were seen, they would most likely, if at all, only attract passing notice, and so probably elsewhere. Fragmentary rocks of any nature would convey nothing to the majority of people, and only some structural peculiarity would take their interest. A fact which lends some strength to this theory is the occurrence under very much the same condition of somewhat similar bodies elsewhere, as the Moldavites or Bouteillenstein of Bohemia and the glass balls of Billiton described by Verbeek, who also includes these objects in the same category. Among more uncertain occurrence might be mentioned one described by Karl Emil Kluge.[1] Under the Bouteillenstein variety of obsidian he states that such green-bottle balls come from India. They are from two to two-and-a-half inches in diameter, and are as hard as quartz. In the interior are found cavities about the size of large peas. Whilst one of them was being sliced by a Paris lapidary, the half which was not secured burst with a hissing sound and a detonation that resembled the bursting of "Rupert's drops." The specimens described by Beudant from Mount Patko, on account of their close resemblance, might also be included provisionally.

Considered as meteorites, then, their extraordinary manner of distribution is at once satisfactorily explained, and their surface sculpture is also consistent with such an hypothesis, it not having been met with on any undoubted terrestrial rocks; but, beyond this, we have nothing but negative evidence in its favour, and unless an actual fall is observed, it is quite apparent that its advocacy must be almost entirely based upon such evidence. It is, therefore, important that all other possible explanations should be thoroughly investigated and exhausted. If this is done, and they are all dismissed as untenable, we should, I think, be justified in attributing a cosmic origin to them.

In conclusion, I have to thank Mr. T. S. Hall and others who have kindly rendered me assistance in the preparation of this paper.

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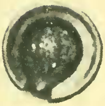

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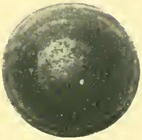

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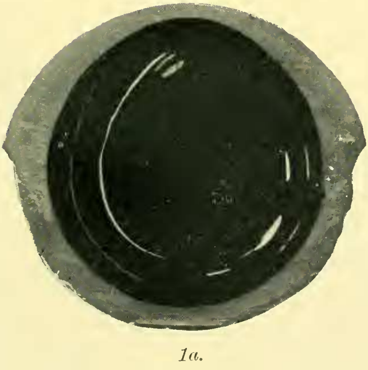

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